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# THE GEOLOGY OF THE LOWER WERRIBEE RIVER, VICTORIA

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## Abstract

The Werribee River downstream of the Bacchus Marsh basin has cut a gorge through an extensive lava field consisting of older sheet-flows, probably poured out from an east-west fault-fissure, and younger tongue-flows from central vents of various types. For the succession of basalt flows and interbedded pyroclastics the name 'Exford Volcanics' is proposed. The Exford Volcanics are up to 400 feet thick and rest on the slightly eroded surface of Tertiary marine clays, sands and limestone of Balcombian age. The surface of the lava field has been so little eroded as to constitute a virgin volcanic terrain, displaying many features characteristic of a basaltic lava field. This lava field occupies the north-western corner of the Port Phillip Sunkland and it is suggested that the north-eastern boundary of that Sunkland is a fault, running north-north-west through Williamstown, for which the name 'Gellibrand Fault' is proposed.

## Introduction

The Lower Werribee River runs from Bacchus Marsh, 32 miles W.N.W. of Melbourne, to Port Phillip Bay, a distance of about 25 miles. The general direction of flow is south-easterly, and after leaving the Bacchus Marsh basin the river flows in a narrow gorge about 100 feet deep through a lava plain.

The area described in detail was surveyed geologically for the State Rivers and Water Supply Commission as the first part of a geological survey of the Werribee River catchment area, for purposes of water supply and soil conservation.

The geological plan was based on the parish plans of the Victorian Lands Department. Traverses were made by pace and compass, and levels were obtained by surveying aneroid corrected by means of a barograph. Form lines were drawn in the field and therefore the contours, though not accurate, give a good representation of the shape of the surface. Bore records of the Mines Department were used in drawing the sections.

## Previous Work

The Lower Werribee River area was mapped by the Geological Survey of Victoria in 1860 to 1861. Published Quarter Sheets covering this area comprise numbers 8 S.W., 20 N.E., 20 S.E., and 20 N.W.

Despite its proximity to Melbourne, this area received no further attention from geologists until 1902, when Kitson described the area, including a list of fossils found in ejected blocks on Mount Mary. In the same year Thiele and Grant listed the fossils from the clays above the lignite in the Altona coal shaft and correlated these deposits with the clays of Balcombes Bay.

In 1918 Fenner wrote a long and detailed account of the physiography of the Werribee River catchment. He described the Rowsley Fault in detail and briefly mentioned the volcanoes of the lower plains but did not describe them. In 1924 he described the Bacchus Marsh basin and its development.

Keble mentioned the extensive lava field of the Werribee plains in his paper on lava residuals in 1918.


FIG. 1.—Geological Map. Rectangle outlines area shown in Fig. 2.

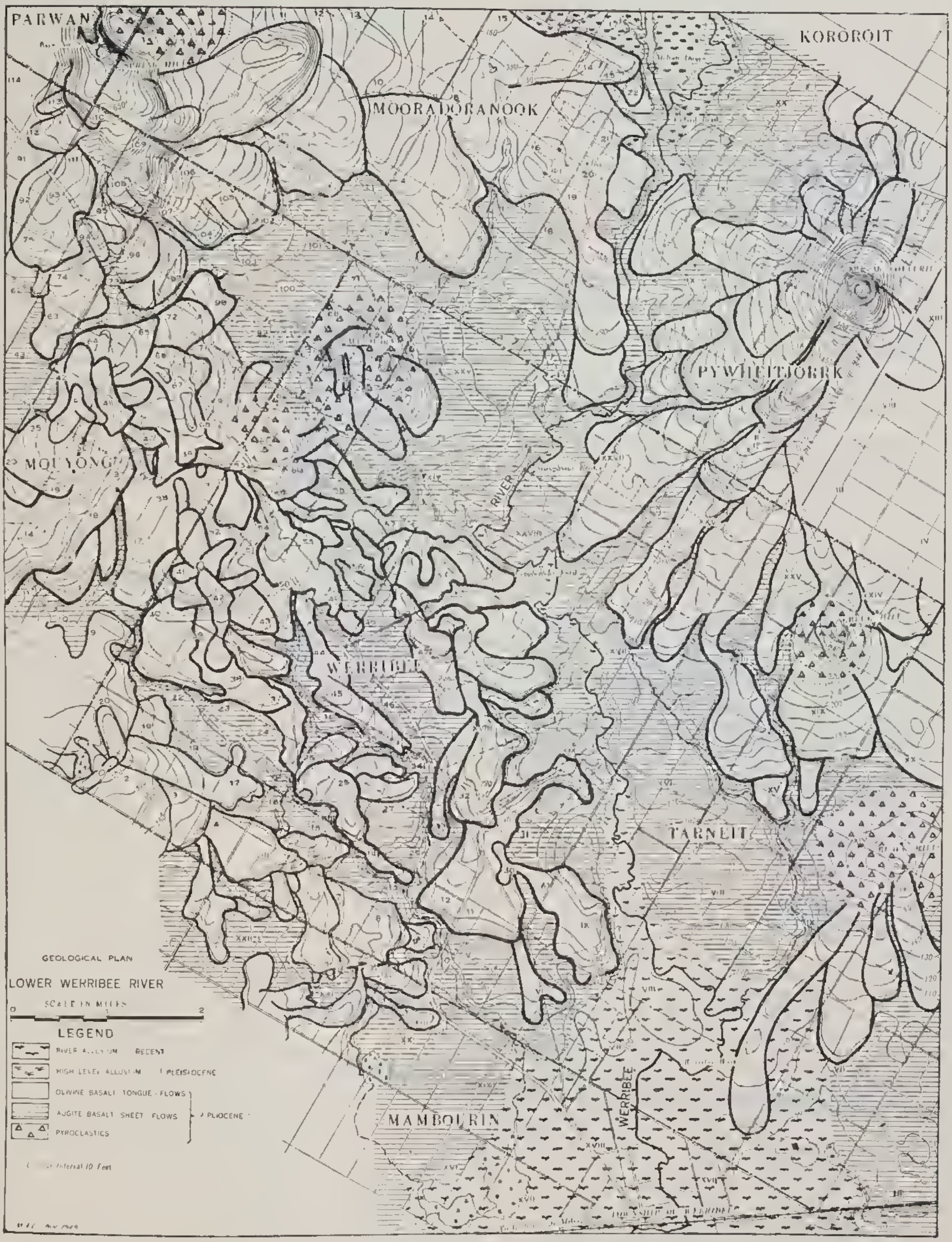


FIG. 2.—Geological Plan, Lower Werribee River.

Herman in 1922 mentioned the Werribee lignites in his report on Victorian brown coals, stating that the Altona lignite has Oligocene marine beds above and below it, but did not discuss the reason for the statement.

Coulson in 1938 described the two main types of basalt in the area—the Olivine Basalt (Ballan Type) of the vents and tongue-flows and the Augite Basalt of the lower sheet-flows—and placed them both in the Pleistocene.

Hills mentioned the basalt of the Bacchus Marsh district in his paper on the age of the Cainozoic Volcanic rocks of Victoria (1939). He stated that these basalts are almost certainly Pliocene.

Singleton (1941) in his "Tertiary Geology of Australia" described the lignites, sands and clays of the Parwan-Altona area as Oligocene, overlain by marine Balcombian clay and limestone.

Parr listed typical Balcombian foraminifera assemblages from limestone above the top lignite and from clay between the top and main lignite seams (1942).

Kenny in 1947 described the Bacchus Marsh Coal Mine, Parwan, where development work had been done on two seams of brown coal prior to the outbreak of fire.

Forbes in 1948 described the soil erosion in the catchment above the Melton Reservoir.

Thomas and Baragwanath (1949) mentioned the Altona-Parwan brown coal in describing the brown coals of Victoria.

## Structural Geology

The valley of the Werribee River, downstream of Bacchus Marsh, forms part of the large structural unit known as the Port Phillip Sunkland. This is essentially a fault trough, the boundary faults being the Rowsley Fault to the west, the Selwyn Fault to the east, and to the north a group of poorly-defined faults running roughly from Darley to Whittlesea. There is probably another boundary fault running from near Frankston north-north-west through Williamstown. To the east of this line there are extensive outcrops of Cainozoic sediments of Balcombian and Kalimnan age, and of Silurian bedrock. For some distance to the west of this line from Williamstown to Gisborne, only Newer Volcanics outcrop. Bores at West Newport

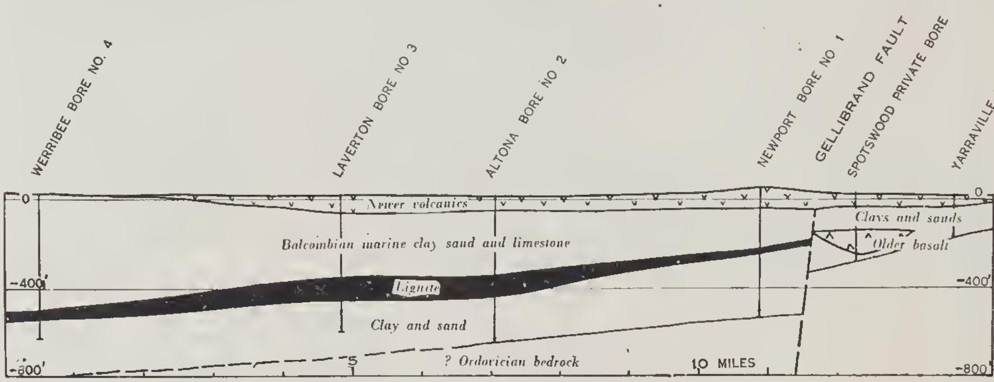


FIG. 3.—Sketch Section, Werribee to Yarraville.

and Altona show Balcombian sediments down to 330 feet below sea level and bedrock at 550 feet below sea level (Fig. 3). This level in the Newport bore is 350 feet below the level of the bedrock in the Yarraville bore 3 miles to the north-east.

This difference is quite at variance with the gradients of the bedrock between the Newport and Altona bores and between the Yarraville and Spotswood bores and appears to indicate the presence of a fault with a throw in the Tertiary sediments of about 150 feet. The name 'Gellibrand Fault' (from Point Gellibrand at the south end of the Williamstown peninsula) is proposed for this fault. The southern projection of the line of this fault passes along the steep eastern shore of Port Phillip Bay and (on the south-east side of the Selwyn Fault) passes to the north of the Ordovician sediments in the Mornington Peninsula. The extension of this line to the north passes through the very marked concentration of points of eruption in the Gisborne district and is in line with the Elphinstone-Harcourt edge of the Mount Alexander granodiorite. It seems possible that the Gellibrand Fault may be a Palaeozoic fault of large throw causing at least part of the displacement of the Ordovician-Silurian boundary from near Sydenham to the Mornington Peninsula.

The Port Phillip Sunkland is of late Tertiary origin, although the boundary faults developed at different times: the northern group and the Gellibrand Fault in the Palaeozoic, Selwyn's Fault in early Tertiary and Rowsley Fault in late Tertiary times.

## The Drainage System and Its Development

The Lower Werribee River flows easterly from Bacchus Marsh to Exford and then south-south-easterly to Port Phillip Bay. The Lerderderg River and Coimadai Creek enter the river from the north and the Parwan Creek from the south within the Bacchus Marsh basin. The Djerriwarrh and Toolern Creeks enter the river from the north between the basin and Exford. There are no significant tributaries downstream of Toolern Creek.

The valley of the Werribee River is markedly asymmetrical about the river both as to areas and topography and, apart from the accident of naming, it is obvious that the main stream above the Bacchus Marsh basin is the Lederderg.

The author agrees with Fenner in ascribing the development of the Bacchus Marsh basin to river erosion in the soft Tertiary sediments (Fenner 1919, 1925), but prefers another interpretation of the history of the drainage system. The coastal plain of Tertiary sediments almost certainly had a marked effect on the form of the pre-Newer Volcanic drainage. The edge of this plain was along a line from near Lal Lal in the west to Coimadai and thence to near Keilor. On the surface of the coastal plain the courses of the streams would be determined by the general southerly slope, by the position of streams reaching the coastal plain from the highlands and by minor depressions in the surface of the plain. There are many flows, both confined flows and sheet-flows and tongue-flows of unconfined type, in the Newer Volcanic episode.

With these facts in mind, the physiographic history of the Werribee catchment may be set out as follows:

1. Development of a peneplain probably continuing into early Tertiary times.
2. Uplift and commencement of dissection of the peneplain by the rivers already established on its surface.
3. The Tertiary Port Phillip sedimentary basin was initiated as a fresh water basin in which were deposited sands, clays and vegetable material which later formed lignite.
4. Older volcanic lava flows filled some of the valleys on the land surface.
5. Further subsidence caused a marine invasion of the Port Phillip basin and the deposition of the Balcombian and Kalminan clays, limestones and sands.
6. These sediments were exposed by uplift and the main streams developed

inherited courses as extended consequent streams on the southerly-sloping surface of the resulting coastal plain, which stretched southward from about the latitude of Ballan.

At this stage, it seems reasonably certain that the ancestor of the Upper Werribee, above Ballan, joined by the Korweinguboora and Korjamumnip Creeks, flowed over the plain to meet the Moorabool near Morrison's; that the Dales, Korobeit, and Myrniong Creeks entered on the plain independently as very small streams and finally joined one or other of the main streams far to the south; and that the Lerderderg River and the 'Ancient Djerriwarrh' and 'Ancient Coimadai' Creeks maintained independent southerly courses over the coastal plain. In the soft Tertiary sediments, the valleys cut by these streams would be narrow and deep. Such a valley, filled with basalt and cut through by the Werribee, occurs just below the mouth of the Korkuperrimul Creek. It is probably the valley cut into the Tertiary sediments by the 'Ancient Lerderderg' River.

7. The Newer Volcanic episode commenced, the early flows rapidly filling the narrow valleys in the Tertiary sediments and spreading out as sheet flows. As a result the shape of the resulting surface was determined more by the locations of the vents and the general slope of the surface of the coastal plain than by the position of the former valleys, except in the bedrock area where the valleys were well-defined, with high interfluves. In these valleys, lateral streams (Keble 1918)—Werribee, Myrniong, Korkuperrimul, Goodmans, Pyrete, Djerriwarrh—developed at the edge of confined lava flows. All the streams from Ballan to Korkuperrimul were diverted to the east by the basalt, and joined together, and the new stream (the Upper Werribee of the present) joined with the Lerderderg to flow south over the sheet flows which still reflected the slope of the underlying coastal plain.

8. At about this stage, the Rowsley, Greendale and Spring Creek faults became active and scarps were developed along these faults with consequent increased activity of streams on the upthrow blocks and deposition of extensive fault aprons at the base of the scarps.

9. The easterly course of the Werribee below Bacchus Marsh was not established until the late stages of vulcanicity when tongue-flows were poured out from Bald Hill (Balliang East) and Spring Hill. These flows blocked the south-flowing streams which were forced to develop an easterly course along the northern margin of the numerous tongue flows from these two vents. The diversion was almost repeated by a junction of flows from Spring Hill and Mount Cotteril but after forming a lake, the river, now joined with the Coimadai, Djerriwarrh and Toolern Creeks, was able to cut through the basalt bar and establish a course which was largely determined by the interdigitating tongue-flows from Spring Hill and other vents on the west and Mount Cotteril on the east. Westerly flows from Bald Hill also turned the Parwan Creek into the Werribee at this stage.

10. While the river was slowly cutting down through the hard basalt in the sections between the mouth of the Djerriwarrh Creek and Werribee township, the five streams in the Bacchus Marsh area were able to cut out the wide basin in the soft Tertiary sediments. By this time, the Rowsley scarp was well developed and the streams flowing over it were actively eroding deep gorges. Material from this source and from the attack on the sides of the Bacchus Marsh basin provided abrasive material for the river's attack on the basalt, which was further helped by the eustatic drop in sea level during the Pleistocene ice ages.

11. A subsequent rise in sea level caused alluviation of the lower part of the river valley and the formation of a deltaic deposit downstream from about 3 miles north of Werribee. Later fluctuations of sea level exposed much of this delta and

caused the river to cut a deep channel through this alluvium, caused alluviation of this channel and erosion through this newer alluvium. These fluctuations of sea level were probably accompanied by fluctuations in rainfall, high sea level (caused by high global temperatures melting the polar ice caps) being accompanied by high rainfall.

## The Physiography of the Cobbledicks Ford District

This district is a lava plain with volcanic hills. The surface is divided between very rocky areas and areas of rich red soil, the latter being used for growing hay, the former only for grazing sheep. Along the river, the alluvial flats support small dairy herds and have been developed in some places into market gardens. The population is sparse especially to the west of the river where a large part of the surface is occupied by outcropping basalt. There are no flowing streams on the plain surface and stock must depend on rain water trapped in small dams or on ground water raised by windmill. The ground water is brackish but quite suitable for sheep. In most of the district the only vegetation is grass, either native or introduced, with an occasional she-oke. These are some areas of well-grown eucalypt (grey box), but over most of the plain the only trees are those in small plantations. These appear to grow reasonably well, and provide valuable shelter for stock. More general planting of trees as wind-breaks would help to reduce wind velocities at the surface, and thus minimize wind erosion which, while not very obvious, is occurring.

### (1) The Volcanic Hills

The most obvious feature of the landscape is the number of isolated hills. These have a variety of forms which may be included in three main types, as follows:

(a) *The lava cone.* Mount Cotteril is an almost perfect example of the volcanic cone in which the shape is that of the geometric cone. In the case of Cotteril, this form has been achieved by the radial arrangement of a great number of tongue flows, with practically no explosive phase intervening. The lip of the crater has been built up first in one part and then in another, so that the flows were fairly evenly distributed around the circumference, and, in this way, the cone was built up equally on all sides. It is possible that the core of this hill may be of scoria, as without an initially elevated crater, it is unlikely that a cone would be developed.

(b) *The lava dome.* There are several hills in the district which have the form of a lava dome. The biggest of these is Spring Hill (R.L. 700 feet). Smaller examples include One Tree Hill (505 feet) in Crown Allotment 42, Parish of Mouyong, and the unnamed hills in Crown Allotments 41 and 52, and in Crown Allotment 1, Parish of Werribee. The geometric form of the lava dome is a segment of a sphere, and is thought to be due to the building up of the dome, particularly in its early stages, exclusively from lava. In nearly all cases, there is evidence of explosive activity late in the building of the dome, but this does not affect the general shape.

(c) *The scoria dome.* There are no pure scoria hills in this district, but the two hills of Mount Mary (Plate I, fig. 3) and Black Hill are essentially scoria domes with but few flows of lava.

Geometrically, the scoria dome is a segment of a sphere. Typically it rises very abruptly from the country on which it rests, has steep sides and flattish top.

Besides these three main types, the following, though smaller, are distinct, in origin and form.

(d) *Parasitic cone.* On the south-east flank of Spring Hill is a small parasitic lava dome, with later flows from Spring Hill diverted around it. There are several parasitic vents which have not developed cones. These small domeshaped outcrops of hard, columnar basalt are not lava blisters since they have no connection with the flows through which they protrude, and usually occur close to a well-established vent. It is thought that they are probably small parasitic vents which never quite succeeded in extruding lava. Examples include one in C.A. 42, Parish of Mouyong (west of One Tree Hill), one in C.A. 51, Parish of Werribee, and three close together in C.A. 14, 19 and 20, Parish of Mouyong.

(e) *Lava ridge.* Running from Crown Allotment 58 to Crown Allotment 20B, Parish of Werribee, is a ridge of lava up to 30 feet above the adjoining country. This ridge, which has several low saddles, has no traceable connection with any point of eruption, although several small flows appear to originate at the ridge. It appears possible that this ridge has developed from a fissure-vent. In the same line, but further to the west, a small scoria dome occurs (in Crown Allotment 62, Parish of Werribee). This may be on the same fissure, but at this point the activity has been chiefly explosive (although a few small flows occur).

(f) *Lava blister.* In several cases, near the distal end of a tongue-flow, a low hill of lava occurs, in obvious continuity with the flow which surrounds it (e.g. in Crown Allotment A of Section XX). This is believed to be due to the arching up of the solidified outer surface of the flow by the pressure of still-fluid lava within and presupposes the development of a lava tunnel along the flow to give the necessary pressure.

On the crests of Mount Cotteril and Greek Hill there is an interesting structure. At the top of Mount Cotteril there is a steep face of hard dense basalt some 15 to 20 feet high. The top surface of this basalt dips in towards the centre of the crest, generally at low angles but on the north side at an agle of about 30°. Near the centre of the saucer-shaped crest is a thin flow of basalt with centripetal dip. At Greek Hill the interbedded basalt flows and scoria appear in a steep face on the north-eastern side dipping towards the south-west at about 10°. Two thin flows with centripetal dip can be followed around in a circular outcrop, but lower flows, outcropping in the face, do not outcrop elsewhere.

There appear to be several possible explanations. First, that the steep-sided cap was originally surrounded by tuff which has since been eroded away, that in the final stage of activity the lava solidified in the vent without overflowing, and then collapsed in the centre when lava withdrew from below. However, the evidence in the district is of very little erosion of pyroclastic material even on steep slopes.

Secondly, much the same series of events may have occurred, without any pyroclastic rim, and then either the central plug was forced up some 20 feet above the last lip, or the sides of the cone settled by that amount, the plug remaining stationary.

Finally, there is a possibility that the structure may be due to the upwelling and partial withdrawal of near-solid lava which was too viscous to overflow.

The upthrusting of the plug after the last effusive activity would account for almost all of the observed features on both Mount Cotteril and Greek Hill.

Edwards and Crawford (1940) ascribed rather similar steep-sided caps in the Gisborne district to erosion. Although the Gisborne cones are possibly older than those in the Exford district, and erosion has been effective in the basalt of the Gisborne district, it seems possible that those caps are of similar origin to that of Mount Cotteril.

It has been suggested (Thomas 1948) that these inward-dipping structures are 'diatremes.' By definition however, a diatreme is a hole, cylindrical or funnel-shaped, drilled through solid rock by gaseous explosion (Daubree 1890). Evidence of a funnel-shaped vent does not alone establish the existence of a diatreme. Since at both Mount Cotteril and Greek Hill a vent had been in existence during the building of a large lava cone and a composite cone respectively, the term 'diatreme' is not applicable to this structure. Both Hack (1942) and Rust (1937) describe diatremes, respectively funnel-shaped (occupied by sediments and lava flows) and cylindrical (filled with agglomerate). This does not depart from Daubree's original nomenclature. In most of the vents of the Werribee Plains, the throat consists of a lower diatreme (opened by explosion) and an upper part built up by successive flows and pyroclastics. Exceptions to this, where the diatreme is at the surface, include the crater at the north end of Spring Hill and the double crater two miles north-west of that.

## (2) Depressions

Almost as characteristic of the lava plain as the hills, although not as obvious, the numerous depressions are diverse in form and in mode of origin. The main types are as follows:

(a) *Subsidence depressions.* This depression is usually very shallow as compared with its area, often large (e.g. 40 acres in lot A16, Mooradoranook), and usually occurs on the top surface of a tongue-flow. Sections XI and XX, Pywheitjorrk, have some fourteen of these subsidence depressions. They are caused by the sagging of the surface which can result from the collapse of a tunnel in the basalt beneath, or by consolidation of underlying tuff beds. They are sometimes scattered apparently at random, but in some cases appear to have a definite linear arrangement (e.g. those in sections 27 and 28, Tarneit). It may be that this linear arrangement is a reflection of a lava tunnel, the roof of which has collapsed at a number of points along its length. As against this, no definite evidence of tunnel formation has been seen in the river gorge, so that the linear arrangement may be accidental.

(b) *Interflow depressions.* These are usually flat-bottomed and surrounded by lava flows. They occur where flows either from different vents or from the same vent approach one another, but meet only at isolated points, so that an area of the older surface is left exposed between the flows and becomes a swamp because there is no outlet to the drainage. Examples include depressions in Crown Allotments 63 and 9-10, Parish of Mouyong, 18, 25 and XIX A Werribee, XX D Tarneit.

(c) *Craters.* Most of the vents do not have any crater, but on the north flank of Spring Hill there is a large crater, probably in part at least, due to explosion at a late stage in the eruptive history of this volcano. To the north of this also, there is a large double crater, the road from Exford to Balliang passing along the ridge between the two craters.

(d) *Sites of former hot springs* (Plate I, fig. 3). Scattered over the surface of the lava plain are small depressions, which are very consistent in form. They consist of a depression up to several acres in area, but usually less than one acre and often only 20 feet in diameter. The depression is from one to two feet deep (below the level of the surrounding surface). The bottom of the depression consists of black or grey clay or clay loam usually with nodules of magnesite, sometimes with small boulders and fragments of basalt, usually limonite-coated. On the downhill side of the depression, or in very level areas completely surrounding it, is a level ridge of black clay loam up to one foot above the adjoining surface of the plains. From its characteristics, it is suggested that this type of depression is the site of former hot springs or fumeroles of the dying phase of vulcanicity. The low ridge is thought to be due to the transfer of soil from the water channel to the point where, on account of the very gentle slope, the velocity of the water would be reduced. The difference in colour and texture between this feature and the surrounding soil is thought to be due to chemical change brought about by materials dissolved in the hot water. There is usually no sign of sand either in the depression or in the soil of the ridge—an indication that the large particles of sand probably sank into the water channel and only the finer clay and silt particles were carried by the water of the spring. No features which could be ascribed to geyser action were seen, and it is thought that if these had existed the evidence would still exist since in general there has been little erosive destruction of minor features in the surface soil. Some of the deeper 'hot spring' depressions, particularly those with a definite water-course leading away from them, may be sites of geysers, but definite evidence is lacking. The water of the springs which formed these depressions is thought of as having been hot because under ground water conditions which exist and which were probably similar when the springs were flowing, positive pressure from below would be required to bring the water to the surface from the water table, which is generally only slightly above sea level, and up to 200 feet below the surface, where these spring sites occur. The only likely cause of this pressure is steam produced by the residual heat of vulcanicity. The water tends to be carried to the surface up the vertical joint cracks by steam bubbles, in much the same way as an air-lift pump lifts water by means of compressed air (Addison 1934). The steam bubbles in order to persist must be in equilibrium with the surrounding water which, therefore, must be close to the boiling point, and which would be kept at that temperature by the supply of superheated steam from below.

There is no deposit of travertine or other precipitate around the depressions. The magnesite nodules in the soil may have derived from the water of the hot springs.

### (3) The River Gorge

The Werribee River flows in a steep-sided gorge cut through the gently undulating lava plain. The course of the river, as of even the smallest water-courses on the plain, has been pre-determined by the final shape of the lava field. In general, the lower course of the river was determined by the flows from Bald Hill, Spring Hill and Mount Cotteril. Flows from the two former forced the river along to the east and a relatively low gap between the Spring Hill flows and the Cotteril flows determined its southerly course. The final course between the outlet from the Bacchus Marsh flats and Exford was established in the alluvial material deposited in the basalt-dammed lake which covered this area. The detailed position of the gorge is essentially superimposed on the older sheet flows through which it is cut, having being determined by small differences in level in the alluvium, when the lake was drained by erosion of the basalt bar, which was located in Crown Allotment X, Pywheitjorrk, and Allotment 20 of A, Mooradoranook. From this point, the river developed as a lateral stream at the edge of the more recent flows from Spring Hill, Cotteril, Black Hill and the numerous small vents in the Parish of Werribee. In the vertical-jointed basalt cut horizontally by beds of tuff and scoria, it is thought that the main erosive activity was probably waterfall erosion such as can be seen in the hanging valleys of the smaller tributary gullies in this district. It seems likely that there would be developed a series of waterfalls each one initiated by a bar of hard basalt. There is some indication of this in the profile of some of the spurs, but only in the Toolern Creek is there very good evidence in the form of large flat shoulders high above the river bed. There has been little erosion of the gorge since the deposition, in the bottom, of the older alluvium. Prior to this, the river was entrenched in a pseudo-meandrine course—the meanders having no relation to the graded condition of a flood plain tract, but being produced by the interfingering

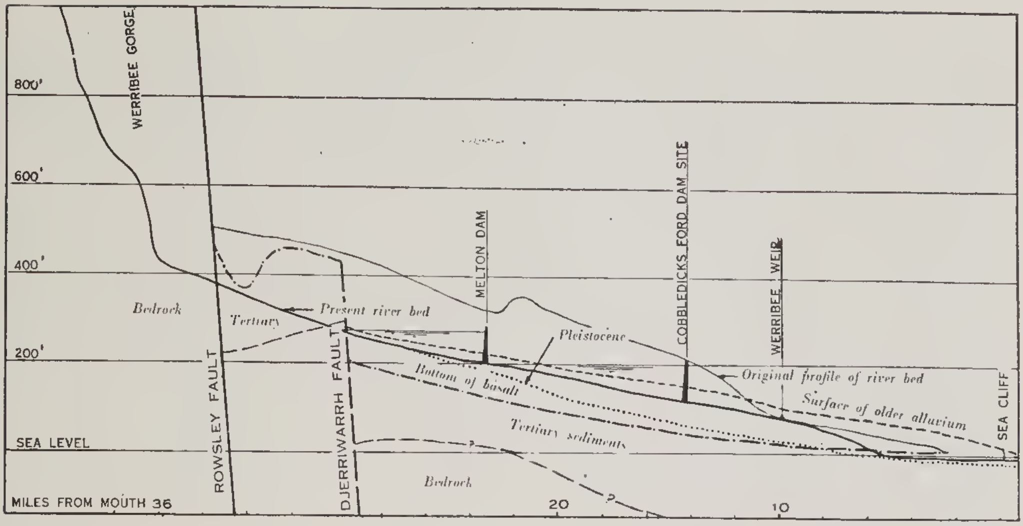


FIG. 4.—River Profiles Past and Present.

of flows from either side. The 'meanders' were actively migrating downstream and many sharpened spurs resulted, e.g. Crown Allotments 27B, 28D and 28C, in the Parish of Tarneit. Since the deposition of the older alluvium, the energy of the river has been so reduced that no further migration has taken place. The older alluvium forms a terrace some 30 feet above river bed. A lower terrace some 20 feet above river bed occurs in the newer alluvium. A third terrace, in the newer alluvium, about 10 feet above river bed, has been covered by recent floods and is still in process of formation.

### (4) MINOR DRAINAGE

The minor drainage, on the surface of the lava plain, is essentially radial to the vents. The individual watercourses, in which water flows only after heavy, high-intensity rain, are lateral to the tongue-flows which generally radiate from the vent. Where sheet-flows form the plain surface the drainage is more haphazard, being determined by minor irregularities in the surface. The scoria hills have very little effect on the drainage—a reflection of the permeability of the scoria, rain usually soaking in rather than running off.

## Geology of the Lower Werribee Valley

### ORDOVICIAN SEDIMENTARY ROCKS

Thin-bedded slates and sandstones of Lower Ordovician age outcrop in the valley of the Djerriwarrh Creek almost to its junction with the Werribee River and at the bottom of the steep slopes at the east end of the Bacchus Marsh basin. The fault junction between the Lower and Upper Ordovician sediments runs along the valley of the Djerriwarrh Creek. The nature of the bedrock beneath the Werribee Plains is not known. The presence of large fragments of reef quartz in the basalt in some places suggests that the bedrock is of Ordovician sediments with their accompanying quartz reefs. No fragments of Ordovician sediments were observed in the basalt or pyroclastics.

## Tertiary Sediments

Unconformably overlying the Ordovician sediments is a deposit of fresh-water and marine sediments, up to 700 feet thick. Sources of information about these sediments include the Mines Department logs of bores at Newport, Altona, Werribee, Parwan and Mouyong; the list of fossils described from the first Altona coal shaft (Thiele and Grant 1902); ejected blocks found on Mount Mary in the Parish of Werribee (Kitson 1902); Parr's description of the fauna from Bore No. 7, Parwan (Parr 1942); and outcrops in the Bacchus Marsh basin. The list of fossils from the Altona coal shaft includes 203 species of Mollusca, 180 of which occur at the type locality of the Balcombian Stage (Hall and Pritchard 1902). Ejected blocks from Mount Mary, in which fossils are poorly preserved, contain sufficient well-preserved casts to establish the Balcombian age of these blocks (Kitson 1902). The material from the Altona coal shaft certainly came from above the coal, and is separated from it by a 'coarse water-worn gravel' which is unfossiliferous. Herman (1922) states that the Altona coal has marine Oligocene both above and below it. Singleton (1941) states that 'it is likely that the bulk of the Yallourn series is pre-Miocene as are probably the lignites, sands and clays of Altona and Parwan,' and that 'though all occurrences of lignites are not necessarily on the same horizon, in general they agree in being antecedent in the main to the principal or Barwonian marine deposits, and it is, therefore, not unreasonable to refer the bulk of the lignite series to the Oligocene.' W. J. Parr (1942) described the micro-fauna from Bore No. 7, Parish of Parwan, where, in a cream limestone and grey clay above the upper ligneous clay, he found a foraminiferal assemblage typical of the Balcombian Stage, including Lepidocyclines from the limestones. The Balcombian fauna was repeated in another bed of grey clay beneath this ligneous clay. This would appear to fix the Altona-Parwan coal as part of the Balcombian Stage, and to point to an alternation of marine and estuarine conditions in this area during the Balcombian Age.

## The Newer Volcanic Rocks

The Newer Volcanic rocks of the Lower Werribee Valley comprise basalts of closely related types, and pyroclastics—tuff, scoria and agglomerate in thin beds between flows. The Newer Volcanic period of activity in Victoria probably commenced in the Pliocene Epoch and continued, with some quiet periods, into the Recent Epoch (Hills 1939). The vulcanicity was undoubtedly connected with the earth movements which elevated much of south-eastern Australia to its present height and produced such large faults as the Bogong Fault, the Rowsley Fault and many of the Gippsland faults. There are two distinct phases in the vulcanicity here as elsewhere in Victoria (Mahony and Grayson 1910)—the earlier phase of sheet-flows, probably from fissure vents, and the later phase of tongue-flows from central vents. The Lower Werribee area is an excellent example of an extensive lava field (Keble 1918), having completely covered the pre-basaltic surface.

(a) The earlier phase: The vents from which the earlier flows poured out are not known. There is a progressive thinning of these lower flows from north to south along the gorge of the Werribee River between Exford and Cobbledicks Ford. The lower tongue-flows from Mount Cotteril and Spring Hill flowed chiefly to the north and south indicating that the surface of the sheet-flows probably sloped in these directions from these points. These vents were possibly situated on an east-west ridge (above a fissure vent). The linear arrangement of the volcanic vents of Spring Hill, Mount Cotteril and Mount Atkinson makes it appear possible that a fault zone and extrusion channel could occur along that line. However, no sign of such a vent (Fuller 1927) has been seen in the river gorge downstream of Melton Dam. The earlier phase of volcanic activity is characterized by widespread sheet-flows of large horizontal dimensions, but thin (up to 50 feet thick) in relation to their extent. As the surface over which these flows travelled was the very gently-sloping coastal plain of the raised marine sediments, the very great extent of these flows implies very great fluidity in the lava, as well as the extrusion of very large volumes of lava in a short time. The two conditions would be mutually helpful since rapid extrusion of large volumes of lava would lessen the degree of cooling in the passage through the crust and tend to produce hotter and, therefore, more fluid lava at the surface, and the more fluid lava would be more readily poured out at relatively high velocities. These earlier basalts contained large amounts of gas—as shown by the very vesicular nature of the chilled base and top of the flows—and this gas would help to maintain the fluidity of the lava. There are several distinct sheet-flows in this area, usually with tuff, scoria or agglomerate between the individual flows. Between two of these sheet flows there is a fossil soil with the horizons of a mature soil and buckshot gravel near the surface indicating that there were appreciable intervals between individual extrusions. The sheet-flows are chiefly of pyroxene basalt, although the lower flows are of olivine basalt.

(b) Later phase: At a late stage in the period of vulcanicity, volcanic cones were built up around relatively small crater-vents. These cones are of four types—lava cones (Mount Cotteril), lava domes (Spring Hill), scoria cones (Mount Mary), and composite cones (Black Hill). They are the most conspicuous feature of the lava-plain landscape, standing out prominently in spite of their low height—only some 400 feet above the surrounding plain. The olivine and iddingsite basalt from these cones were poured out in the form of tongue-flows of relatively small volume, elongated in the direction of travel and with a thickness appreciable in relation to width (up to 5 per cent). A characteristic of these tongue-flows is that, at least toward the distal end, they stand up above the older surface with quite steep sides and front, but fairly flat top, so that they are tongue-shaped in section as well as in plan. The rocks of this later phase have been so little affected by erosion that the individual flows can be traced quite clearly. The only places where erosion is marked is along the river gorge and along some of the tributaries.

'Exford Volcanics'

Resting on the eroded surface of the unconsolidated marine clays and sands of possibly Kalimnan age is a succession of basalt, tuff and agglomerate for which the name Exford Volcanics is proposed. The name is taken from the property between the Werribee River and the Toolern Creek at their junction. The Exford Volcanics, outcropping in the Werribee River gorge downstream of Melton Dam and on the plain on either side of the river, comprise sheet-flows of olivine basalt, augite basalt and iddingsite basalt and tongue-flows of olivine basalt together with thin beds of pyroclastics between flows. Maximum total thickness is about 600 feet at Mount Cotteril. They are almost certainly Upper Pliocene in age but may range into the earliest Pleistocene (Hills 1939).

Details of the succession through the Exford Volcanics, from oldest to youngest, follow:

(a) Resting on the marine sediments is a deposit of tuff of variable thickness (up to 11 feet in Bore 4, Mooradoranook) probably representing the explosive phase which often initiates a volcanic period.

(b) Above this and also very variable in thickness (up to 50 feet thick) is a sheet-flow of olivine basalt which filled the valleys of the streams crossing the coastal plain, and spread out across much of the plain. The top of this flow is exposed in the bed of the creek which enters the Werribee River in section XXIV B, Parish of Werribee. Here it is hard, dense, only slightly oxidized, grey in colour, with small phenocrysts of light green olivine. It probably corresponds with the 'hard basalt' recorded in many bores at the bottom of the volcanic rocks.

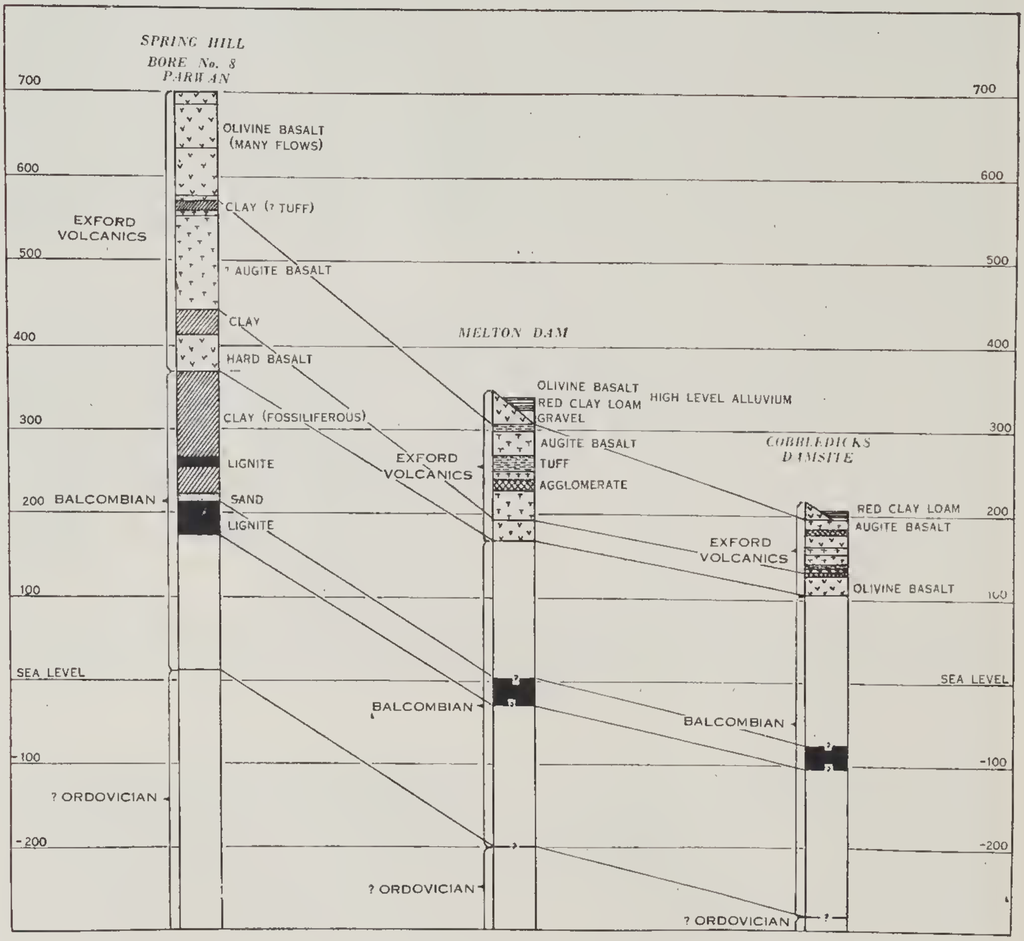


FIG. 5.—Stratigraphical Columns.

(c) Resting on the surface of the olivine basalt is the lowest flow of augite-basalt, usually between 20 and 30 feet thick. Where exposed, this flow is usually decomposed with only fresh plums remaining in the friable brown decomposed basalt. A good exposure of slightly weathered rock occurs in the lower part of the spillway of the Melton Dam. The fresh rock is hard, dense, dark green and medium-grained crystalline, although the chilled lower selvedge shows very few phenocrysts, indicating that the crystallization occurred after extrusion. The top surface of the flow is very vesicular and is usually less decomposed than the body of the flow.

(d) On top of the lowest augite basalt rests a deposit of tuff and clay varying in thickness from 6 inches to 12 feet. The top part of this deposit is a fossil soil derived from tuff. Typical profile is as follows: Up to 4 feet of tuff usually red, and sometimes 'prismatic' consisting of polygonal prisms up to 1 inch in diameter, and up to 1 foot long. This tuff rests on the surface of the lowest augite-basalt, and in places has entered along joint cracks to a depth of 10 feet. The tuff passes up gradually into a red-brown clay subsoil up to 2 feet thick which in turn passes up into a yellowish clay soil up to 2 feet thick and then into a whitish soil (up to 1 foot thick) with much buckshot gravel. The development of this mature soil necessitates a rather lengthy period free of volcanic activity. In a few places quartz gravel with pebbles up to 1 inch diameter rests on the surface of this soil. The importance of this fossil soil lies in its demonstration that the newer volcanic period was not one of uninterrupted activity such as has been assumed by some writers, but that not only were there many and separate flows, but also periods of quiet, during which processes of erosion and deposition would continue without superimposed effects of vulcanicity.

(e) Resting on the surface of the fossil soil and usually 'baking' it for a depth of 2 or 3 inches is the thickest flow in the succession, the second augite-basalt flow. This flow, of titan-augite basalt, is about 50 feet thick at Exford, but thins towards the south so that at Cobbledicks Ford it is only 15 feet thick. A common feature of the lower part of this flow is a development of tachylitic pillow basalt. The pillows are up to 18 inches in diameter, with up to 2 inches of tachylite on the surface of each pillow.

The pillows show characteristic radial jointing. The tachylite is weathered yellow on the outside, but is mostly very fresh. This feature is very well seen on the right side of the Toolern Creek Valley just upstream of the Exford Bridge (Plate I, fig. 5). Similar exposures occur at intervals down the gorge and appear to be associated with thick developments of the fossil soil in areas which are relatively low.

Below the pillow lava near Exford Bridge there are quartz gravels resting on the surface of the fossil soil.

It is probable that these places were water-courses prior to the outpouring of this flow, and that damming of the streams by small tongue-flows just prior to the main outpouring produced small lakes into which the basalt was extruded from the chilled advancing end of the lava. These pillow lavas are very significant in respect of water storage since they may continue for appreciable distances, and are very pervious. This type occurs near and downstream of the junction of Toolern Creek and the Werribee River, on the left side of the river valley in lot A of 27, Parish of Tarneit, and on the right side of the river valley just downstream of Cobbledicks Ford. The basalt of this flow in general is decomposed with fresh residual plums of hard, dark green, crystalline basalt. Where the pillow lava does not occur, the bottom of the flow is very vesicular, and usually the vesicles are filled with carbonates. The top of the flow is usually very vesicular and a feature of the flow as a whole is the amount of foundered skin which occurs, sometimes giving the appearance of separate flows. In a few exposures in the river gorge, the upper part of this flow is hard, oxidized and columnar, so that it seems possible that the more generally observed decomposed rock is a surface development.

(f) Resting on the vesicular surface of the second augite-basalt sheet-flow is a well developed zone of pyroclastics—up to 3 feet of scoriaceous agglomerate at the bottom, 1 to 10 feet of well-bedded tuff and lapilli above (Plate I, fig. 4). The agglomerate is rather sporadic in occurrence. In its thicker occurrences (as at

Staughtons Bridge) it consists of pieces of scoriaceous and dense basalt up to 3 inches in diameter in a dark red-brown ground mass of tuff, clay and volcanic glass. The bedded tuff is of a buff colour in beds from about 6 inches to $\frac{1}{8}$ inch thick. The thicker beds consist of scoriaceous yellow tachylite, basalt fragments, fragments of quartz and sandstone, waterworn quartz sand, and mineral fragments. The thinner beds contain the same constituents in smaller size. In a few cases there is some grading from coarse to fine. The general appearance of the material is very pervious, and not consistent with deposition under water. Furthermore, the bedding follows irregularities in the underlying surface with very little variation in thickness, so that it can be stated with confidence that this material is a sub-aerial deposit, and that such sorting as does occur is due to the variation in rates of settling through the air. There is no sign of weathering in the top layers of this deposit, which, therefore, must have been exposed for only a short time before the next flow covered it. This zone is rather pervious and likely to cause losses by seepage from a reservoir. The bedded tuff is a relatively weak rock, although it does have 40 feet of basalt (equalling about 50 lbs. per square inch) resting on it without noticeable failure.

(g) On top of the bedded tuff, and apparently following it with very little time-break, is the upper flow of titan-augite basalt—generally hard, oxidized and columnar, but occasionally showing the complete decomposition of the lower flows. This flow is rather thin near Exford, but thickens southward, increasing from about 15 feet at Exford to some 30 feet at Cobbledicks Ford. Like the other augite-basalt flows, it has a dense centre and a vesicular top and bottom, the latter usually chilled. This flow contains many fragments of reef quartz.

(h) A bed of scoria up to 3 feet thick rests on the surface of the upper augite-basalt flow. This consists of rough, scoriaceous basalt blocks up to 6 inches in diameter in a very open arrangement.

(i) The very ropy and scoriaceous bottom of the lower flow of iddingsite basalt rests on the bed of scoria. This flow is from 5 to 20 feet thick, is often very decomposed in its outcrop, and usually shows platy as well as columnar jointing. The rock is generally vesicular, is dark grey when fresh, and contains phenocrysts of iddingsite up to 5 mm. in diameter. It outcrops at or just below the lip of the gorge all the way between Melton Dam and Staughtons Bridge.

(j) Above the lower iddingsite basalt is a second flow of similar type. Usually there is no pyroclastic rock between, although in places a thin layer of scoria occurs. The upper iddingsite basalt is from 5 to 10 feet thick, generally less weathered than the lower, hard, dark grey, vesicular, columnar and somewhat platy, although not as noticeably as the lower flow. Like the lower flow, it contains phenocrysts of iddingsite, but also contains some olivine.

(k) A thin layer of tuff or scoria usually occurs between the upper flow of iddingsite basalt and the flow of olivine basalt which occurs above it. In the cliff face of the river gorge, olivine basalt occurs in discontinuous outcrop, where the ends of flows from either side have been cut by the river. At no place is there evidence of the same flow of olivine basalt occurring on both sides of the valley—the river everywhere has developed around the edge of the flow and has nowhere cut across it. The olivine basalt is a hard, microvesicular blue-grey rock with small phenocrysts of olivine many of which are iddingsitized. The rock is usually quite fresh, and jointed into columns up to 6 feet in diameter. As many as three flows can be seen in the exposed face on the valley side, although many more flows occur nearer the points of eruption. The olivine basalt is the most suitable rock for use as concrete aggregate or for rock fill, since it is unweathered, whereas most of the other types are generally not fresh.

As will be seen from the above description of the volcanic rock sequence, there is relatively little variation in petrological type in this district. This is in marked contrast to the Gisborne district, where a much smaller eruptive phase was productive of many more types (Edwards and Crawford 1940). The reason for this may be found in the examination of the chilled selvedges of the various flows which give an approximate picture of the state of crystallization of the lava when it was poured out. The selvedge of the middle augite-basalt flow shows very small phenocrysts of augite and iddingsitized olivine in a dark glass. This indicates that crystallization had not progressed very far before extrusion and that, therefore, differentiation had not become effective. This is an indication that the temperature of the magma was sufficiently high to prevent crystallization of alkali minerals, and that a channel was opened to the surface otherwise than by cupola development. It is suggested that one or more of the faults in the Port Phillip Sunkland opened a channel between the magma and the surface and allowed the extrusion of vast amounts of undifferentiated and uncrystallized 'olivine-basalt magma' which, because of its high temperature and great fluidity, covered large areas as sheet-flows before crystallizing and coming to rest. The main channel may have been the eastward extension of the Spring Creek Fault at the south of the Ballan Sunkland, along the line of which the later vents of Bald Hill, Spring Hill, Mount Mary and Greek Hill are located.

*Weathering*

Basalt, because of its mineralogical composition and open jointing, is very susceptible to rapid weathering. The iron oxides, olivine and mineral glass which occur quite generally are very rapidly oxidized when meteoric solutions come in contact with them, and because of the columnar jointing, the interior of flows is subject to the attack of surface water more quickly than are most other rock types. This rapidity of weathering is reflected in the condition of the basalt. Badly weathered and slightly weathered flows are interbedded, while the freshest flow of all is the olivine basalt of the tongue-flows on the plain on either side of the gorge. In general, it is probable that the more decomposed flows were exposed at the surface for a relatively long time before being covered by the later flow while the less weathered flows were covered almost immediately by the flow above, and in this way protected from attack by surface water. The olivine basalt at the surface probably owes its freshness to the relatively short period which has elapsed since its extrusion. In the fresh basalt, much of the iron present is ferrous iron (about 7 per cent. of the rock is FeO). When weathering starts, the iron is oxidized and the lime and magnesia is almost entirely removed (McCance 1932). Some of this is probably reprecipitated in vesicles as geodes, but most of it is carried away in the ground water and is the reason for the brackish nature of that water. The oxidation of the olivines and hydration of the iron ores produce internal stresses in the rock, which cause minute cracks which further help the access of water to the interior of the rock. Continued oxidation and hydration produce disintegration of the rock into its component minerals and results in the friable brown decomposed rock which is so typical of the weathering of basalt (the 'salamander' of quarry-men). None of the basalt of this district has been weathered to a clay in the way that many of the older basalts have.

An interesting feature related to the weathering is the variation in soil development. On slopes which face from south-east to westerly there is generally a relatively good cover of dark humous clay loam, while on slopes facing north-west to easterly there is only a cover of rock debris with very little soil or vegetation. As this difference is not related either to rock type or to slope (except that very steep slopes are generally barren), it is believed to be due first to the greater amount of rain received on the slopes facing generally south-westerly, as compared with those facing generally north-easterly (most heavy rain in this district coming from the south and west), and secondly, to the lower evaporation from the slopes facing south-westerly which do not receive so much direct sunshine and are not exposed to the hot drying north winds of summer.

*Jointing*

. All of the flows exposed at the damsite have been jointed into rough columns although, in the more decomposed flows, the joints are largely lost in the general disintegration of the rocks. Basalt solidifies at a temperature of about 1000° Centigrade, and since the thermal coefficient of expansion of basalt is about 0·000005 per degree Fahrenheit, the linear contraction involved in cooling to air temperature would be about 1 per cent. Hence, with joint columns about 5 feet in diameter, the joints would be about ½ inch wide. This gives the physical reason for the vertical jointing in basalt—vertical contraction can take place without cracking, but in the relatively great horizontal dimension of a flow, the contraction cannot occur by movement over the surface, and, therefore, cracking along vertical planes occurs. The joint cracks are open equally throughout the flow, and are one of the reasons for the demonstrated permeability of basalt in the mass. For the same reason, a basalt flow has practically no tensile strength in a horizontal direction, although its compressional strength, particularly in the vertical sense, is quite high (about 18,000 lbs. per square inch).

*Permeability*

The total interconnected void space in jointed basalt, as indicated above, is about 2 per cent. of the volume of the flow, or about 1 per cent. of the area of a vertical section. These percentages may be reduced by the infilling of the joints by clay or secondary mineral deposit. An important feature of these joint cracks in relation to permeability is their relative uniformity (as compared for instance with the voids in a gravel). As a result of this, the permeability of basalt is much higher than the void ratio might indicate. Confirmative evidence of the high permeability of the basalt in this district is seen in the level and gradient of the water table. Between Bore No. 1, Kororiot, and Bore No. 1, Pywheitjorrk, there is a difference of level in the water table of 84 feet in a distance of 180 chains, a gradient of less than 1 per cent. The gradient between Bore No. 1, Pywheitjorrk, and the river 80 chains to the west (0·3 per cent.) is thought to be due to the river having developed a perched water table above the general surface of the ground water in the basalt.

In relation to the storage, the joint space in the basalt can cause appreciable initial losses, and there is almost certain to be a continual loss to the ground water, until such time as the basin is covered by a layer of silt. The ground water level is generally at, or slightly below, river level—there is apparently very little flow from the ground water into the stream. When water is stored to full supply level, there would be a difference in level between the stored water and the ground water of up to 100 feet, with the consequent possibility of steep hydraulic gradients and large water losses. Some of the water would be recoverable when the level of stored water fell, but much would pass into the ground water and flow directly to Port Phillip Bay as such. From Exford to Cobbledicks Ford there are a number of outcrops of tachylitic pillow basalt. These are probably located in an old watercourse. The farthest downstream of these outcrops seen, at R.L. 180 feet in the valley wall immediately to the south-east of the Cobbledicks Ford, would provide a very pervious channel for water stored to R.L. 200 feet. The Melton Reservoir does not give a satisfactory comparison to the Cobbledicks storage in relation to losses through the basalt, since the basalt outcropping in the Melton storage is nearly everywhere decomposed so that the joints are closed. Such losses as occur are probably due to permeable scoria layers, although there is evidence, in Bore No. 2, Mooradoranook, of a gravel-filled deep lead which may draw water from the reservoir.

*Stability*

As stated above, the hard fresh basalt is very strong in vertical compression, but the vertical joints make it very weak in tension. The horizontal flows with pyroclastic material between them, in addition to the strength characteristics of the basalt, make the volcanic series very susceptible to slip failure, which is further encouraged by the tendency towards very steep slopes being developed by erosion. Landslips are quite characteristic of the valley sides and as they have occurred so frequently under natural conditions, it is most likely that under the conditions imposed by the storage many more landslips will develop.

*Faulting*

There is no evidence of faulting in the volcanic flows, either at the damsite or in the storage area (between Exford and Cobbledicks Ford), except in one place where there is a displacement of perhaps 10 feet in the middle and lower flows. At the damsite the rocks are reasonably well exposed, so that any major fault would be noticeable in the displacement of flows. The bedded tuff forms a quite valuable marker bed and, although it follows minor irregularities of the older surface, it is sufficiently regular to indicate any major displacement. There are, however, probably many faults of appreciable throw in the underlying Tertiary sediments, as shown in the marked displacement of these beds, with their noticeable lignites, in the two bores, Nos. 7 and 8, Parwan, where there is a vertical displacement of 34 feet in a horizontal distance of 20 chains.

## Post-Basaltic Sediments

(A) *High level alluvium*

Covering the top surface of the basalt from Exford northwards to near Melton Railway Station, westward to Parwan Railway Station, and north-westward to the Melbourne-Ballarat Road on the Djerriwarrh-Coimadai interfluve, is an alluvial deposit consisting of coarse gravel, sand and sandy clay loam of a total maximum thickness of 15 feet (Plate I, fig. 2). The gravel is well rounded and consists of quartz, quartzite, hornfels, and few basalt pebbles. The pebbles range in size up to 9 inches in diameter. The sand, generally above the gravel, is clean quartz sand. Above the sand is a layer of clay loam, which, near the surface, is a dark red-brown sandy clay loam. This deposit rests on the surface of the iddingsite basalt sheet-flows and against the side of some of the olivine basalt tongue-flows. It was probably laid down in a lake formed by the diversion and damming of the Upper Werribee drainage by the tongue-flows from Bald Hill, Spring Hill and Cotteril. This lake overflowed at a point just south of Exford, and as the river cut through the bar at that point, the alluvial deposit was exposed and the streams established courses on the surface of the deposit, and cut through it and into the basalt beneath.

(B) *Clay loam of the lava plain surface*

Covering the entire surface of the basalt, except at the edges of the flows and in the bottom of the larger watercourses, is a deposit of soil of variable thickness (up to 10 feet). The thicker deposits generally occur on the surface of the older sheet-flows, while the surface of the later tongue-flows usually has a much thinner deposit. The profile of the thicker deposits as shown in the road cutting on the east side of the river at Staughtons Bridge is shown in Fig. 6. Resting on the scoriaceous surface of the sheet-flow of augite-basalt is 3 feet of light grey clay with fragments of tuffaceous material, small fragments of basalt and nodules and veins of magnesitic material. It is believed that this clay is a decomposed, very fine tuff, resulting

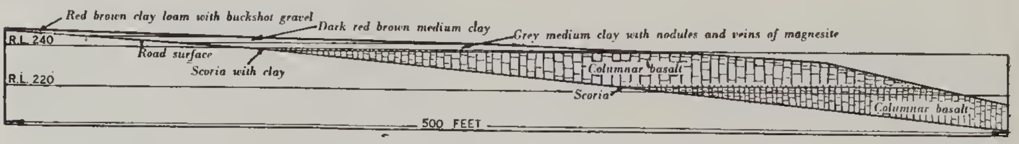


FIG. 6.—Road Cutting, Staughtons Bridge, East Side.

from distant explosive activity. This material is similar to the sticky grey clay which is so characteristic of the surface in the Footscray district, where it has no cover of red clay loam. Above the grey clay at Staughtons Bridge is a layer about 2 feet thick of dark red-brown clay with magnesitic nodules. This appears to be quite a distinct layer and appears to be largely tuffaceous. The surface layer of about 2 feet of red-brown sandy clay loam, in which the sand is a well rounded quartz sand, and which contains buckshot gravel, is probably in part tuffaceous in origin, and in part loessal, part of the sand having been windborne and deposited with the volcanic ash. This sandy clay loam is the only soil which appears on the surface of the later tongue-flows. Much of the sand may have been blown out with the volcanic ash (from the Tertiary sands underlying the basalt), and in this regard it is interesting to note that the proportion of sand in the sandy clay loam increases appreciably in the vicinity of Mount Mary, one of the few large scoria cones in the district. This red-brown clay loam is of vital economic importance to the district, since it is only where it covers the basalt to a sufficient depth that cultivation is possible. It is a rich soil, but very shallow, and it is at present being allowed to erode by wind and water action. The total effect to date is very small, but every strong hot north wind carries a quota of soil from this district to the sea. Erosion by water action is rare as in general the soil is sufficiently pervious to prevent large runoff, but where stock or vehicular traffic compact this soil and prevent absorption of rain, erosion can be very rapid. There are enough small erosion gullies scattered around the district to cause concern to anyone interested in conserving the vital top soil not only for this generation but for many to come. Active measures should be taken to halt the present gullies, and to prevent the development of new ones. In this generally dry area, high intensity rain can do untold damage if positive measures are not taken in advance to reduce the velocity of water running off and particularly to eliminate vertical drops.

(C) *Older alluvium*

An alluvial deposit up to 90 feet thick occupies the bottom of the valleys of the Werribee River and of the Toolern Creek. This deposit, according to evidence from bores at Cobbledicks Ford, has up to 60 feet of sand and coarse waterworn gravel at bottom and up to 30 feet of red brown sandy loam above. The red-brown sandy clay loam overlying the gravel probably was deposited during a period of reduced river flow, as compared with that which carried the gravels. It appears to be a fairly uniform deposit both vertically and in its occurrence along the river valley, although there is a noticeable variation from more sandy to more clayey type from Exford to the Werribee Delta, which is composed chiefly of red-brown clay loam. Near the damsite this deposit is a sandy loam with some layers of clay loam—probably an ideal material for use in a rolled-earth section of the dam. Like the gravel below it, the sandy loam derives chiefly from the bedrock areas to the north and west of the Werribee Plains, and but little from the basalt. Just above the Werribee Weir this deposit has completely filled the valley cut in the basalt, and spread out over the surface of the basalt in the form of a delta. It seems probable that this delta was built up above sea-level as a flood-plain deposit. The deposit shows remarkably little bedding except in its lower levels where beds of sand and gravel appear. No marine fossils were seen, or have been reported. It seems probable that if the delta had been formed under the sea there would have been more obvious bedding and marine shell beds. The eroded valley in the basalt which underlies this delta is filled with gravel and sand, and is continuous with the gravel of the deposit in the gorge. This bed of gravel is an important aquifer and during the drought of 1944-46, when insufficient water for irrigation was available from Melton Reservoir, water from bores penetrating this deep lead enabled production to be maintained on many properties. The water is quite suitable for irrigation in strong contrast to the ground water in the basalt, which has a high salt content. This probably means that the water in this aquifer is derived directly from the river and does not receive an appreciable addition from the ground water, and therefore the hydraulic surface of the water in the aquifer must be at or above that of the adjoining ground water in the basalt. The seaward edge of this delta is being eroded by wave action—one of the few parts of the western shore of Port Phillip Bay which is suffering erosion (Plate I, fig. 1).

(D) *Newer alluvium*

A valley has been cut about 40 feet deep into the older alluvium. This has been refilled to a depth of about 20 feet by an alluvial deposit of grey gravelly sandy loam, clay and sand. This deposit is still being built up, every large flood dropping sand on the surface of the terrace and building up the bed of the river channel. The whole deposit has probably been built up in this way, so that there is no continuity in any of the beds. This alluviation may be connected with a eustatic rise of sea level accompanying the melting of the polar ice caps, which is still progressing.

The river almost never reaches the level of the older alluvial terrace, so that its activity is confined to the valley eroded in the older alluvium. Within this valley the river wanders, and even in the past 100 years has changed course in several places.

(E) *Marine sands and clays*

Along the tidal stretch above the mouth of the river and along parts of the foreshore (east of Little River), there are very recent deposits of sand, peat and clay with marine shells. The deposits nearest the foreshore consist of a beach ridge, some 4 feet above normal high tide level, consisting of quartz sand and broken shells, and on the shoreward side a salt-water swamp with a floor of peaty clay. The beach ridge probably began as a submarine sandbank which was raised above sea level in a storm. The raised sandbank cut off the area behind it except during storms, when large quantities of seaweed were deposited in the flat area behind the sand ridge, producing peat on decomposition. Offshore, sandbanks are forming and their shape in plan and section would appear to conform with the plan and section of the sand ridges at Altona shown by Hills (1940).

## Siltation

The catchment of this proposed reservoir includes some of the worst areas for water-erosion in the State (Forbes 1948). The capacity of Melton Reservoir has been reduced from 19,000 to 15,400 acre-feet in 31 years, a loss of 3,600 acre-feet from a catchment of 424 square miles, or an average loss of 0·013 feet over the whole catchment. There has been as yet no concerted attack on this problem, only emergency measures designed to check stream erosion in the vicinity of roads, structures or valuable land having been undertaken. Although Forbes considers that the Parwan catchment (the worst area in the whole catchment) is 'not necessarily overstocked,' he apparently separates the domestic stock (chiefly sheep) from wild stock (rabbits). In terms of soil conservation this cannot be done, the total use of available vegetation being the important factor. As erosion is progressing, and vegetation regeneration is not occurring, it seems obvious that the area is overstocked.

It may be thought, in terms of the proposed Cobbledicks Ford storage, that Melton Reservoir would act as a silt trap, and that siltation is not likely to be a serious consideration. However, from observation of flood flows past Melton Dam, it seems obvious that a very large amount of the finer sediment, up to sand size, is being carried through the Melton Reservoir and would be dropped in the lower storage.

Unfortunately, there appears to be no quantitative record of the silt content of this flood water. There is only one recorded sample of water from Toolern Creek—the only other contributor to the proposed storage. On April 22, 1947, a flow of 10 cusecs had a suspended solids content of 236 parts per 100,000—an indication that erosion is serious in this part of the catchment also. By far the greatest amount of erosion is effected in very short time during periods of high intensity rainfall and, if only flood flows (of more than 1,000 cusecs) are considered, the average amount of silt dropped in Melton Reservoir from flood flows was 480 parts per 100,000 for the years 1917-1947. This, of course, includes bed-load as well as an unknown part of the body-load. It seems reasonable to assume that flood flows past Melton may carry at least 200 parts per 100,000 of suspended solids, while Toolern Creek's total flow (chiefly of flashy nature) would certainly carry at least as much. Of this, at least 100 parts per 100,000 would be dropped in a reservoir downstream of Melton Dam. As flood flows total about 50 per cent. of total flows, and the average annual flow at Cobbledicks Ford is 50,000 acre-feet, the minimum average annual siltation rate would probably be of the order of 25 acre-feet (about one-quarter the rate for Melton). The lower rate is due to Melton's acting as a trap for the bed-load (boulders and gravel), which forms an appreciable part of the sediment. This rate would make the half-life of this storage some 400 years (under present conditions), but as the half-life of Melton is probably only 100 years from construction, and as with increased sedimentation of the reservoir the percentage of silt carried over increases the actual '50 per cent.-life' of the proposed storage may be as little as 200 years (under present conditions in the catchment). This emphasizes the urgent need for widespread soil conservation measures in this catchment. They should be implemented without delay and long continued, so that the present active erosion may be halted, and proper land usage adopted to prevent a continuation of the history of the past century. Unless this is done, any storage on the Lower Werribee is foredoomed to failure by sedimentation, in an historically short period.

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## Explanation of Plate I

Fig. 1 (State Rivers Registered No. 5098).—Wave-cut cliffs in delta alluvium, Parish of Deutgam.
Fig. 2 (7968).—Gravel pit in high-level alluvium, Section XX, Parish of Pywheitjorrk. (a) Gravel and sand, (b) clay, (c) dark red-brown clay loam.
Fig. 3 (7966-7).—'Hot-spring' depression, Section XX-A, Parish of Werribee. Figure standing in centre of depression. (a) Crescentic mound on lower side, (b) Mount Mary (scoria cone) on skyline.
Fig. 4 (7971).—Bedded tuff, Staughtons Bridge. (a) Agglomerate, (b) bedded tuff.
Fig. 5 (7970).—Pillow basalt, Toolern Creek.